MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2019/2020

EEE 3076 – POWER ELECTRONICS

(LE, EE, CE, NE)

24 OCTOBER 2019
9:00 a.m – 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages including cover page with 4 Questions only.
2. Answer ALL questions. All questions carry equal marks and the distributions of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

a) Figure Q1 (a) shows a converter circuit used to control power level to a resistive load. The operating switching frequency of the circuit is 25 kHz and the duty cycle is 50%.

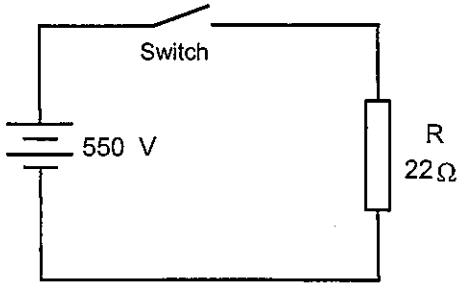

Figure Q1 (a)

(i) Calculate the continuous current through the switch.

[2 marks]

(ii) Select a suitable switch for this application based on datasheets for Switch 1 and Switch 2 given below. Explain why; please give three (3) reasons.

[6 marks]

Datasheet Switch 1: NPN BJT Transistor – MJ10023

Absolute Maximum Ratings:

Collector–Emitter Voltage, V_{CEV}	600V
Collector–Emitter Voltage, $V_{CEO(sus)}$	400V
Emitter–Base Voltage, V_{EBO}	8V
Collector Current, I_C	
Continuous	40A
Peak	80A
Base Current, I_B	20A
Total Power Dissipation, P_D	
T_C = +25°C	250W
Derate Above 25°C	1.43W/°C
T_C = +100°C	143W
Operating Junction Temperature Range, T_J	−65° to +200°C
Storage Temperature Range, T_{stg}	−65° to +200°C
Thermal Resistance, Junction–to–Case, R_{thJC}	0.7°C/W

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Datasheet Switch 2: MOSFET – STW26NM50

Absolute Maximum Ratings:

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source voltage (V_{GS} = 0)	500	V
V_{GS}	Gate-source voltage	±30	V
I_D	Drain current (continuous) at T_C = 25 °C	30	A
I_D	Drain current (continuous) at T_C = 100 °C	18.9	A
I_{DM} (1)	Drain current (pulsed)	120	A
P_{TOT}	Total dissipation at T_C = 25 °C	313	W
	Derating factor	2.5	W/°C
$V_{ESD(G-S)}$	Gate source ESD (HBM-C=100 pF, R=1.5 kΩ)	6000	V
dv/dt (2)	Peak diode recovery voltage slope	15	V/ns
T_{stg}	Storage temperature	-55 to 150	°C
T_j	Max. operating junction temperature	150	°C

b) A power MOSFET with the electrical characteristics as shown below is used as a switch for a DC-DC converter connected to an inductive load. The input voltage is 200 V and maximum output current is 20 A. The switch is operated at 30 kHz with 50% duty cycle.

(i) Static Loss. [6 marks]
(ii) Dynamic Loss. [9 marks]
(iii) Total Loss. [2 marks]

On/off States

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	I_D = 250 µA, V_{GS} = 0	500			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = Max rating V_{DS} = Max rating, T_C=125 °C			10 100	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ± 20 V			± 10	µA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	3	4	5	V
$R_{DS(on)}$	Static drain-source on resistance	V_{GS} = 10 V, I_D = 13 A		0.10	0.12	Ω

Switching times

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on delay time	V_{DD} = 250 V, I_D = 13 A,		28		ns
t_r	Rise time	R_G = 4.7 Ω V_{GS}=10 V		15		ns
$t_{d(off)}$	Turn-off-delay time			13		ns
t_f	Fall time			19		ns

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Question 2

a) Block diagram for a rectifier system is shown in Figure Q2.

(i) Determine type and rating of AC voltage source (Single Phase 230 V, 50 Hz or Three Phase 400 V, 50 Hz) to be used for this rectifier system.

[3 marks]

(ii) Sketch a suitable rectifier circuit for this system.

[5 marks]

(iii) Calculate the load average voltage and current.

[5 marks]

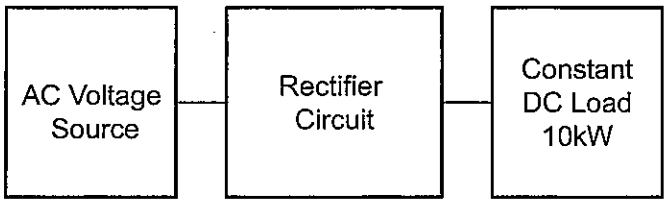

Figure Q2

b) If two similar DC loads as shown in Figure Q2 are connected in parallel.

(i) Sketch a suitable rectifier circuit if the voltage to the load is to be maintained at 200V.

[5 marks]

(ii) Show by calculation on how 200 V can be supplied to the load. Also calculate the current drawn by each load.

[7 marks]

Continued...

Question 3

a) Figure Q3 (a) is a buck converter circuit with input voltage, V_d = 10 V, duty cycle, D = 0.6 and switching period, T_s = 60 µs. Assume that the buck converter will be operating in the continuous current mode and all the components are ideal.

(i) This converter is used to power a load resistor, R_o that consumes 24 W to operate. Find the value of R_o. [3 marks]

(ii) Calculate the inductor, L_B value at the boundary of continuous and discontinuous current mode. [2 marks]

(iii) Select an inductor, L so that the converter will be in the continuous current mode. Then, calculate the maximum inductor current, I_{Lmax} and minimum inductor current, I_{Lmin}. [5 marks]

(iv) The load requires a voltage with ripple not more than 1%. Determine the value of capacitor, C. [3 marks]

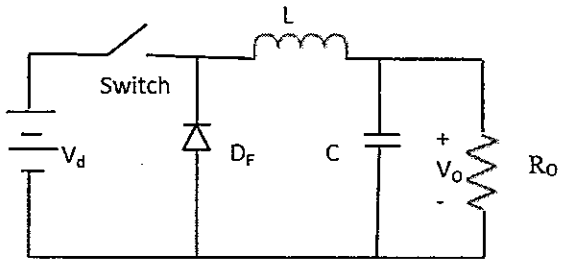

Figure Q3 (a)

b) A flyback converter is shown in Figure Q3 (b). This converter can supply an output power of 100W at V_o =100V from a 50 V input DC source, V_d. The switching freqeuncy, f_s is 50 kHz, the magnetizing inductor L_m is 1 mH and the transformer turns ratio (N_1/N_2) is 3. Determine:

(i) The duty ratio, D. [2 marks]

(ii) The average, the maximum and the minimum inductor current (I_L, I_{Lmax} , I_{Lmin}). [5 marks]

(iii) Sketch the waveforms of the primary of the transformer voltage, v_1 and the inductor current, i_m. (include the values for I_L, I_{Lmax} , I_{Lmin}, V_d and $(-N_1/N_2)\ V_o$) [5 marks]

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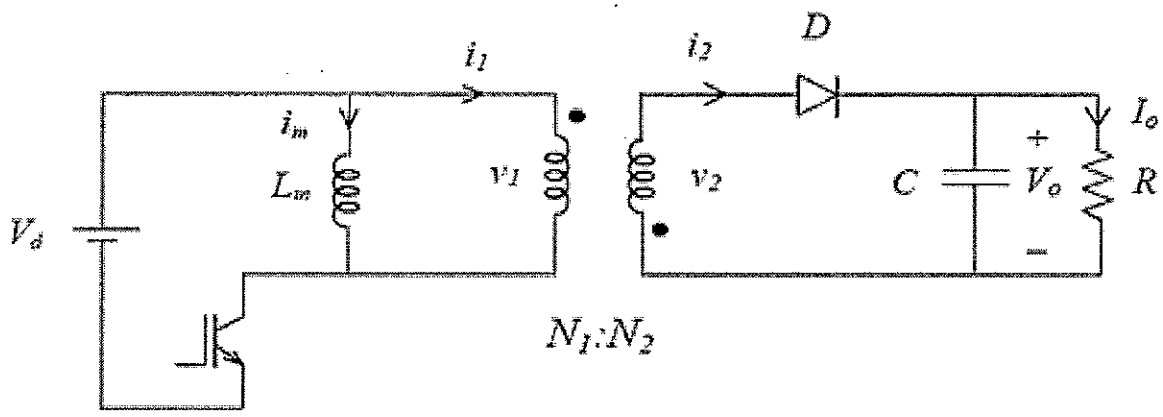

Figure Q3 (b)

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Question 4

a) A full bridge inverter is shown in Figure Q4. The inverter is operating at a duty cycle of 60 % with a frequency of 50 Hz.

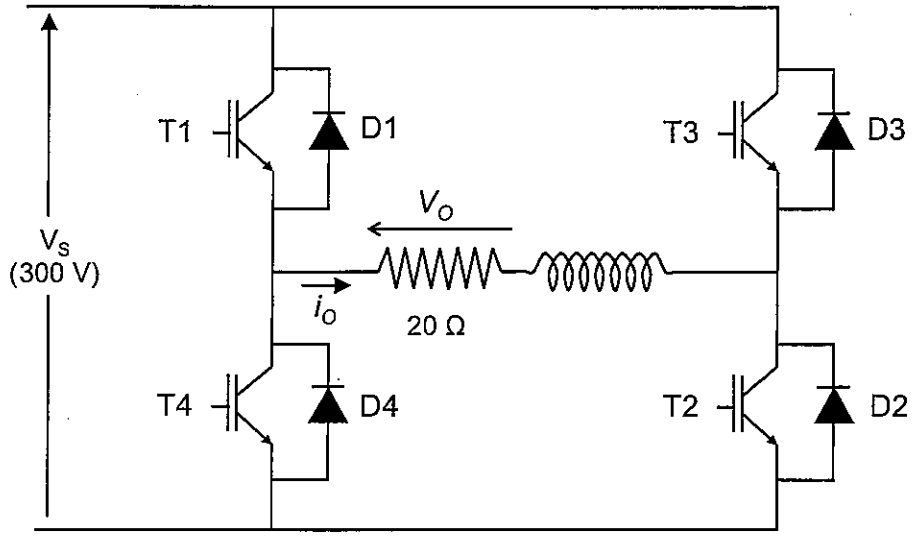

Figure Q4

(i) Calculate the output power considering fundamental, 3rd, 5th and 7th harmonics.
[7 marks]

(ii) In order to minimize high losses in the circuit, the third harmonic was eliminated. Determine the new duty cycle and output power.
[11 marks]

b) A capacitor is connected in series to the load in Figure Q4, (R = 2 Ω, L = 30 μH) Calculate the minimum capacitor value so that the inverter output frequency is 3kHz and operates in overlapping mode.
[7 marks]

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Examination Formula Sheet (Rev 4.0)

AC-DC Converters

Single Phase Uncontrolled Rectifiers (Half wave) , R load	Single Phase Uncontrolled Rectifiers (Half wave), RL Load
$V_{o,avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}$, $V_{o,rms} = = \frac{V_{S,rms}}{\sqrt{2}}$	$V_{o,avg} = \frac{\sqrt{2}V_{s,rms}}{2\pi}[1-\cos(\beta)]$ $V_{o,rms} = \frac{V_{s,rms}}{\sqrt{2\pi}}\sqrt{\beta - \frac{\sin 2\beta}{2}}$ $\beta \approx \pi + \theta$, $\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$
Single Phase Uncontrolled Rectifiers (Bridge Full wave)	Three Phase Uncontrolled Rectifiers (Half wave)
$V_{o,avg} = \frac{2\sqrt{2}V_{s,rms}}{\pi}$, $V_{o,rms} = V_{s,rms}$	$V_{o_avg} = \frac{3\sqrt{3}V_{l-n}}{\sqrt{2}\pi}$, $V_{0_rms} = 1.19V_{l-n}$
Three Phase Uncontrolled Rectifiers (Full wave)	Single Phase controlled Rectifiers (Half wave)
$V_{0_avg} = \frac{3\sqrt{2}V_{l-l}}{\pi}$, $V_{0_rms} = 0.963\ V_{l-l}$	$V_{0_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(1+\cos\alpha)$ R Load $V_{0_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(\cos\alpha + \cos\beta)$ RL Load
Single Phase controlled Rectifiers (Bridge Full wave)	Three Phase controlled Rectifiers (Half wave)
$V_{0_avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}(1+\cos\alpha)$ R Load $V_{0_avg} = \frac{2\sqrt{2}V}{\pi}\cos\alpha$ RL Load	$V_{0_avg} = \frac{3\sqrt{2}}{2\pi}V_{AN}\left(1+\cos\left(\pi/6+\alpha\right)\right)$
Three Phase controlled Rectifiers (Full wave)	
$V_{0_avg} = \frac{3\sqrt{6}}{\pi}V_{AN}\cos\alpha$	

DC-DC Converters

Buck Converter (CCM)	Buck Converter (DCM)
$V_o = DV_d$ $I_{L\max} = V_o\left[\frac{1}{R} + \frac{(1-D)}{2Lf_s}\right]$ $I_{L\min} = V_o\left[\frac{1}{R} - \frac{(1-D)}{2Lf_s}\right]$	$\frac{V_o}{V_d} = \frac{D}{D+\Delta_1}$ $I_o = \frac{V_d T_s}{2L}D\Delta_1$

Continued...

DC-DC Converters (cont.)

Boost Converter (CCM)	Boost Converter (DCM)
$V_o = \frac{V_d}{1-D}$ $I_{L\max} = \frac{V_d}{(1-D)^2 R} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d}{(1-D)^2 R} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1}$ $I_o = \frac{V_d T_s}{2L} D\Delta_1$
Buck-Boost Converter (CCM)	**Buck-Boost Converter (DCM)**
$V_o = \frac{V_d D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{D}{\Delta_1}$ $I_o = \frac{V_d D}{2 f_s L}(D + \Delta_1) - \frac{D I_o}{\Delta_1}$
Flyback Converter (CCM)	**Flyback Converter (DCM)**
$\frac{V_o}{V_d} = \frac{N_2}{N_1}\frac{D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 + \frac{V_d D T_s}{2L_m}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 - \frac{V_d D T_s}{2L_m}$	$\frac{V_o}{V_d} = D\sqrt{\frac{R}{2 f_s L_m}}$ $I_o = \frac{V_o}{R}$

DC- AC Converters

Single-Phase Half-bridge Inverter with RL load	Resonant Converters
$v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Square Wave) $v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Quasi Square Wave) $v(\omega t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi}\sin\frac{nD\pi}{2}\cos n(\omega t - \frac{D\pi}{2})$	$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ $i(t) = \frac{V_s + V_c}{\omega_r L} e^{-\alpha t}\sin\omega_r t \quad , \ \alpha = \frac{R}{2L}$ $V_c = V_s\left(\frac{e^{2z}-1}{e^{2z}+1}\right), z = \frac{\alpha\pi}{\omega_r}$ $V_{cp} = V_s\left(1 + \frac{2e^{2z}}{e^{2z}+1}\right)$

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